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Application of 'C.A.R.B. financial methodology' analysis for alternative energy technologies into UK housing

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Abstract

Current energy trends in UK housing are reviewed and then assessed by introducing the 'CARB financial analysis' methodology. CARB is an acronym for 'Carbon Abatement', as it evaluates the potential carbon-dioxide reduction from different technologies; 'Relative', as all the technologies examined are dependant on various primary sources; and 'Balance', as the cost of surplus CO_2 is quantified. According to conventional financial analysis, most of the technologies examined have the potential to provide positive returns on the investments especially for those with an environmentally conscious agenda. Further reduction of up to 30% of most installed alternative energy systems cost is required to compete with an investment in, e.g., a UK pension scheme. Using the 'CARB financial analysis' the cost of reducing CO_2 has been quantified, and compared with the potential cost of climate change impact. Conventional installed solar technologies are not financially attractive both with a pay back period calculations and 'CARB financial analysis' under current market costs and governmental subsidy regimes. Heat recovery technologies could be sensible investments, both in financial and environmental terms under particular assumptions; especially if the investment budget is small. The use of cogeneration technologies provides a financial advantage in the attempt to minimise the cost of climate change impact, as pay back period of such investment could be less than 7 yr, and the cost of CO_2 saved could be two to seven times less than the global damage cost of carbon emissions.

Keywords: Carbon dioxide; Alternative energy; 'CARB'; Financial analysis; Housing

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1. Introduction

The built environment presently contributes about 40% of the world's air pollution through energy servicing burning fossil fuels, and in the UK, housing accounts for 28% of the national annual carbon dioxide emissions, of which 53% is due to space heating [1,2]. It is now generally accepted that an increased concentration of CO_2 and other greenhouse gases in the atmosphere will lead to global warming [3]. New climate change scenarios for UK, published by CIBSE and 'Carbon Trust' (October 2004) [4], show that the average annual temperatures across the UK will rise by between 2 and 5 °C by the 2080s, with the amount of warming dependent on future levels of greenhouse gas emissions.

The UK Government has actually set a high voluntary target of a 20% reduction by 2010, further increased from the Kyoto Protocol targets. The 'Energy White Paper' (EWP) (February 2003) [5] defines a long-term strategic vision for energy policy combining UK's environmental, security of supply, competitiveness and social goals. The EWP specifies four goals for UK's energy policy, the first of which was to put all industries on a path to reduce the UK's carbon dioxide emissions by some 60% by 2050, as suggested by the Royal Commission on Environmental Pollution.

The extensive use of fossil fuels for matching the UK's energy needs is the main source of carbon emissions. At the moment, more than 96% of the energy used in the UK is from fossil fuels [6]. With a staggering 60% reduction in building related carbon emissions by 2050, few would dispute that the future need is for the creation and maintenance of more sustainable and energy efficient buildings, incorporating new and renewable technologies. This objective encompasses the entire construction industry from conception, design and construction, to the operation and maintenance of a building and its services [7].

The information provided to the UK public by DTI [8], 'The Carbon Trust' [9] and other organisations, such as 'London Energy Partnership' [10], is well produced and presented and helps architects, planners, designers, decision makers and construction practitioners to understand and set up projects which incorporate new and renewable

energy technologies into buildings' structures, envelope and the environment. For the purposes of this paper the renewable energy technologies examined for integration into buildings, were solar photovoltaic panels (PV), solar panels for water or air heating and micro wind turbines. New technologies for use into dwellings and housing buildings were the micro and mini combined heat and power (CHP) generators, heat recovery (HR) using principles of positive pressure ventilation (PPV) and whole house mechanical ventilation (WHMV). These technologies were defined as 'new' as they had only recently been widely introduced in the market, even if the principles, the theory and the designs were available for more than a decade.

Most of the information available from numerous market-related sources includes initial and construction costs. However, there is little information on life cycle costs with regard to finance, such as investment pay back periods (PBP). For the purposes of this paper, the maximum acceptable PBP of an investment is defined from a market prospective in Table 1. These figures are typical in the UK construction industry, and well approved by housing design practitioners, and developers.

The aim of this paper is:

(a) to identify what reductions of systems' prices would encourage behavioural changes in a context of rising financial acceptance,
(b) to propose a new methodology for the comparison of all the technologies in regards to their environmental implications associated with the replacement of other technologies,
(c) to suggest the most beneficial investment into new and renewables energy technologies.

This study forms part of the Department of Trade and Industry (DTI) sponsored Knowledge Transfer Partnership between Coventry University and Kenneth Holmes Associates Chartered Architects. Kenneth Holmes Associates are responsible for the design and specification of a new project in Coventry. The aim of the project is to develop an environmentally and eco benign "village" consisting of 45 individual dwellings and a block of 133 flats. All the information presented here is part of the project's feasibility study for new and renewable technology systems and has been obtained from numerous manufacturers and analysed under a number of different scenarios.

For the purposes of this analysis the Met Office data for temperature, solar insolation and wind, have been used, as it is the oldest UK database, and the data were measured by terrestrial stations. Climate change has been integrated in the study by considering the

Table 1
Years required for energy technologies to be financially accepted

Pay back period of the investment	The investment is widely accepted as good business and public investment if its PBP is below 3 yr	PBP of an investment into a UK Pension scheme; and, cost effective energy improvement under the proposed requirements of the buildings regulations for existing buildings [11] below 7 yr	PBP of investment of environmental sensitive public, institutions, organisations and establishments below 15 yr

expected rises in temperature in UK as they had been estimated by the UK Climate Impacts Programme (2002) [12] and CIBSE in partnership with 'Carbon Trust' (2004) [13], based on the research and findings of the Hadley Centre (Met Office) and Tyndall Centre.

Electricity and gas prices are major influences on renewable energy technology systems PBP. An average energy cost escalation for the study period had been assumed to be 10%, when the UK construction inflation rate would remain around 6%. The escalation prices were based on analysis of the world historic data of the last 3 decades, and analysis of UK oil price trends of the last 8 yr. Research on European electricity, especially with regards to carbon trading, and natural gas, markets were considered using Ecomonitor, Global Insight and OPEC published reports. It was assumed that the oil Hubbert's Peak will not be reached during the next 20 yr. Financial benefits from Renewable Obligation Certificates (ROCs) have been included in the calculations for electricity production from renewables even for some small projects, as green electricity providers provide financial support even for projects that produce less than 1 MWh/annum.

Future trends of domestic energy demand on separate cases were predicted by examining records available from similar projects of local developers and landlords. Linearity of trends is presumed as data had small record length, sample size, record quality, and there is a lack of composite data sets.

Coventry is situated in the middle of country (in latitude), with temperatures near the country's mean. The average United Kingdom PBP of PV and solar heating base technologies were therefore calculated for this location/latitude.

The simulation of variables was achieved by a number of industry standard simulation tools, and from worksheets specially designed for this project. The available market software includes: Cadlink, PVSyst, Homer, T*SOL Pro 4.03, RETScreen PV2000, WaSP Engineering, RETScreen SAHPM2000, RETScreen SWHPM2000 and Flowvent.

Fig. 1 is a summary of all the energy streams related to the examined dwellings in regards to fossil fuels and renewable energy sources. The grid is used as electricity storage, whilst no storage has been considered for heat. HR systems utilise the instantaneous heat storage capacity of the 'thermal energy cycle'.

Individuals, companies, organisations and associations have totally diverse financial budgets and targets. It is not feasible to define a single financial criterion for approving new or renewable energy technology projects. Table 1 has been defined by analysing projects of the last 5 yr. After 5–10 yr systems' penetration and costs will be still the major barrier. Scenarios for the period between 10 and 25 yr will be completely different as climate change, population change, and lifestyle culture will be altered. Even if the PBP of investment expectation is defined as in Table 1, the elasticity of thresholds is unpredictable. The various approaches suggest that the transfer might be gradual, the longevity of trends is unknown, the accuracy of market penetration is unclear and underlying factors might change.

3. Analysis of outcomes

3.1. PV panels for the production of electricity

In an ideal building-integrated PV installation, land and structural support for PV modules are provided at no additional cost, and the modules in turn replace standard building components. At 2004 prices, the cost of a non-integrated installed system is

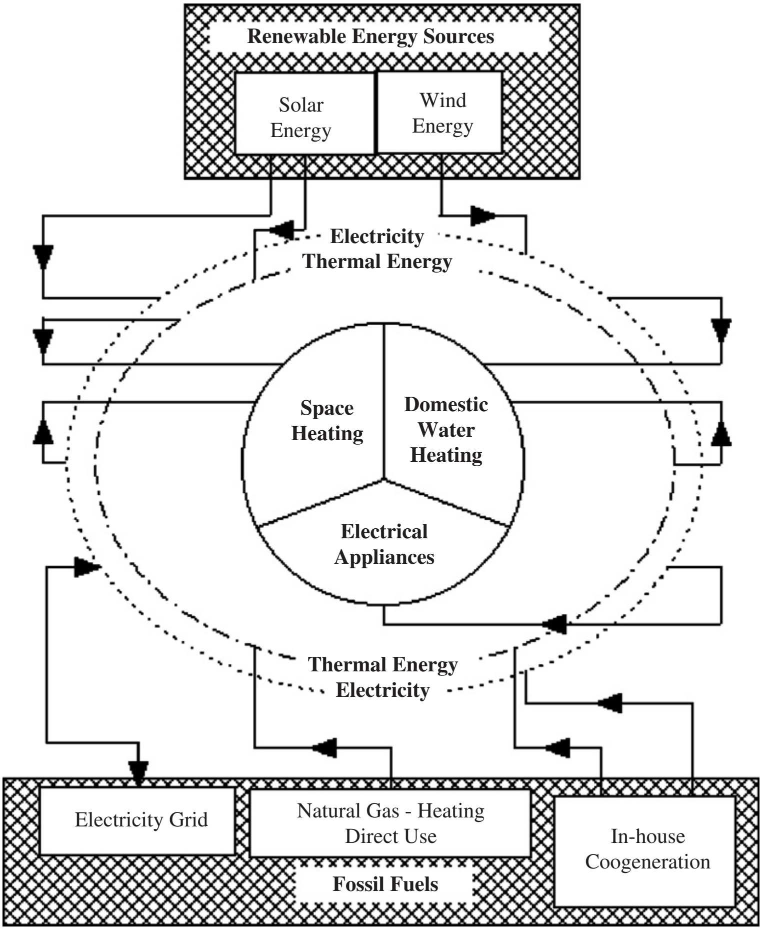

Fig. 1. Definition of energy streams related to housing buildings.

£600–£1200 m^{-2} of panel, due to different technologies used, and usually more than 2.5 m^2 are required for a domestic system. Examining a number of scenarios a mean value of PBP of a grid-connected system is just under 22 yr, i.e. the actual lifetime of the system. The PBP is reduced up to 15 yr if the PV panels replace glazing facades. The PBP is further reduced to 10 yr, and less, if the PV panels replace expensive construction materials, i.e. marble or steel. It has to be mentioned that some marble installations are more expensive than installed fully operational PV systems (Fig. 2).

3.2. Solar panels for the heating of domestic used water

Most solar panels are designed to be 'roof integrated', or easily mounted on roofs. Typical efficiencies are 75–92%. Some evacuated tube designs operate at a higher efficiency than their flat plate counterparts but their cost is much higher. However they do not provide significantly more or less energy over the course of the year [14]. A solar hot water system will reduce the domestic hot water bill by up to 25%/annum, but if it is used

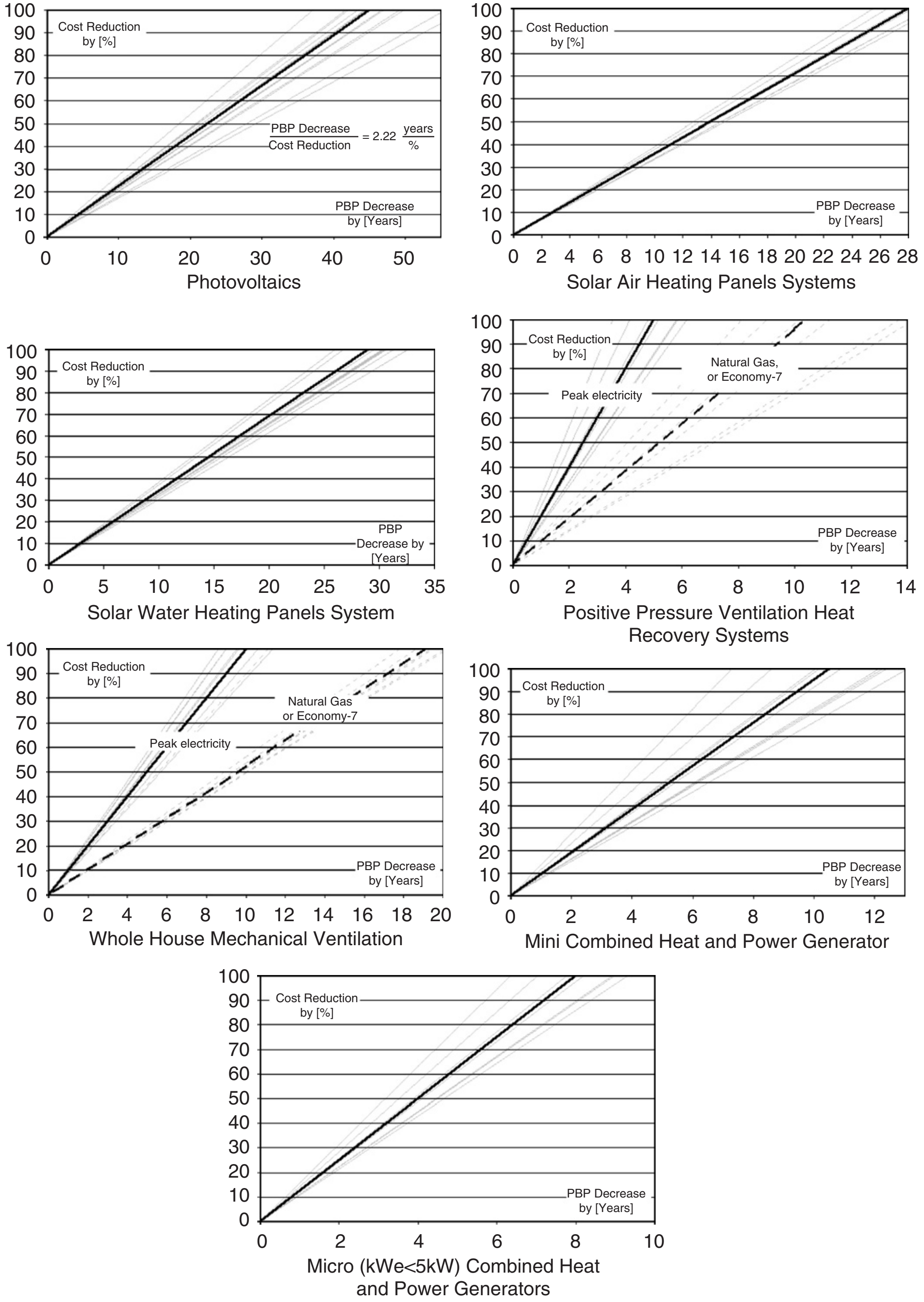

Fig. 2. Sensitivity analysis of housing buildings associated technologies examined.

thoroughly, e.g. in swimming pools from 08:00 till 16:00, the PBP will be further reduced. A typical installed system for domestic use costs around £2300–£2800. Without subsidy, the PBP for a detached dwelling is expected to be 12 yr, if the energy cost is compared with peak electricity or 30 yr if displacing economy gas and economy–7, i.e. off-peak electricity.

3.3. Solar air panels for space and domestic water heating

Two designs are currently marketed. The operation principles of these are:

- *Under the tiles collection of warm air*: The Sun warms the titles/slates, which in turn creates a warm "boundary layer" and heats the area between top of felt and underside of tiles/slates. The mechanism draws air from this area via a plenum fitted to the underside of the rafters and a system of ductwork.
- *Roof mounted solar collectors*: During the heating season they can be used to help heat the home by passing the ventilation air through them before delivery to the dwelling. When heating demand of the home has been satisfied or during the non-heating season, the collectors can heat the hot water.

3.4. Micro and mini wind energy generators (WEG)

Profitability depends on wind speed, cost and performance of a wind turbine installation, as well as energy prices. In, or near, cities and towns the wind speed is dramatically reduced. Most of the horizontal axis WEG do not perform when the wind velocity has a horizontal vector value below 3 m/s. Micro vertical axis WEG would start to operate with wind velocities over 2 m/s. The usage of such systems is therefore limited to remote windy locations. The cost of such equipment is £2000–£3000 per kW installed. These have similar cost, but the efficiency of commercial models is well below that of horizontal axis machines. At these prices, a micro, or mini, wind turbine would be profitable only if the average annual wind speed velocity is above 5–6 m/s.

3.5. HR house mechanical ventilation by positive pressure (PPV)

The simplest form of HR house mechanical ventilation is PPV. Systems of this type use a lower-power fan to draw air into the house continuously, via the roof-space, and supply it to the upper floor. Air is drawn in via the roof-space because heat losses from the house to the roof-space will 'pre-heat' the supply air slightly. Stale air is then allowed to escape from the house, under the positive pressure created by the fan, through trickle ventilators or gaps in the building fabric. HR is involved for the slight pre-heating of supply air as it passes through the roof-space; note that the pre-heating effect will be small in a house with a cold loft above well-insulated ceiling, i.e. existing and expected new building regulations [15]. The typical cost of such systems is £400–£500, with a PBP of 3–7 yr competing against peak electric heating, and 7.5–15 yr against natural gas heating, or economy–7 electricity.

3.6. HR whole house mechanical ventilation (MVHR)

A MVHR system extracts moist, stale air, from kitchens and bathrooms, and supplies filtered fresh air. The extracted air is passed through a heat exchanger where some of the

heat is transferred to the incoming fresh air. The heat exchanger is connected by ductwork to input and exhaust terminals at roof level, and to supply and extract grilles within the house. A MVHR system has high HR efficiencies, but the running cost of a continous supply for the extract fans reduces the resultant fuel cost saving. High-temperature cooling required in buildings can be also provided by MVHR systems. Typical cost of such systems is $\approx$£1100, with a PBP of 6–14 yr competing against peak priced electric heating, and 15–25 yr against natural gas heating and economy–7.

3.7. Mini CHP generators

The design of a mini-CHP requires analysis of the anticipated electric and heating load. They are connected to the grid, and roughly defined as >3.7 kWe, <25 kWe three-phase (upper limit flexible). The cost of a 5 kWe installed unit is in the region of £11,000–£14,000 depending on the construction requirements of the installation. Mini-CHP generators PBP are further reduced if the operation time is increased. Such units may operate only 16 h per day, as the reduced night tariff makes such units uncompetitive at night. The PBP is 9–12 yr with expected lifetimes of around 14 yr. This is based on 80,000 h expected operation time. The reduction in CO_2 is estimated to be 6 tonne/annum.

3.8. Micro CHP generators

The external design and sizes of micro CHP generators is similar to a condensing boiler. Micro generators are designed for domestic scale electricity generation; they could also be connected to the grid. The cost of the micro CHP is not yet available, but is expected to be in the region of £1500. The PBP for new installations is expected to be between 7 and 9 yr. The calculations are based on current electricity and gas prices for a new installation with a "two-way" electricity meter. Considering the replacement of an existing fully operational condensing boiler with micro CHP the pay back time is 14–19 yr. These PBPs may be reduced by up to 3 yr if the "two way" electricity meter is installed. In this situation some of the electricity could be fed back to grid, without any profit for the owner. It is quite difficult to guess what will be the amount of electricity fed back to the grid. A domestic CHP unit installed in a large house might export only in short periods over the course of a year, while the same unit installed in a small flat might export for several hours each day.

4. 'CARB financial methodology' analysis

When the initial consideration for a project is based on installed systems costs, the life cycle financial assessment will influence the approval of project's investment. A typical 'financial life cycle costs' analysis will provide all the information in the cash flow of the investment. A comparison of the actual potential for carbon dioxide reduction is not clear. The CARB analysis is then required to provide a perspective on both financial and environmental costs of different technologies under different scenarios.

4.1. Conventional financial life cycle costs analysis

In Table 2 a summary of the research and its outcomes is collated and analysed. For each technology the PBP is defined under different regimes (Fig. 3). If any additional

Table 2
Financial thresholds for alternative technology investments into housing developments

Technology	The mean life expectancy (yr)	The mean PBP under existing prices without any subsidies (yr)	Current funding (% of the purchase systems' cost)	Reduction due to existing funding (yr)	PBP after current funding (yr)	Further reduction of cost required to be accepted as:		
						Investment of environmental sensitive public, institutions, organisations and establishments (%)	Equivalent investment to a UK pension scheme; and, cost effective energy improvement under the proposed requirements of the buildings regulations for existing buildings (%)	Investment that is widely accepted as good business and public investment (%)
Photovoltaic panels (not BiPV)	25[a]	45	up to 50	23	22	19	36	44
Solar panels for water heating	25[a]	29	30 (+25)[b]	9 (+7)[b]	20 (or 13)[b]	17 (or None)[b]	45 (or 21)[b]	58 (or 35)[b]
Solar panels for air heating: Type A	20[a]	14	—	—	14	None	50	75
Solar panels for air heating: Type B	20[a]	25	30 (+25)[b]	8 (+7)[b]	17 (or 10)[b]	7 (or None)[b]	35 (or 11)[b]	58 (or 35)[b]
Positive pressure ventilation with heat recovery	20[a]	11.25	—	—	11.25	None	39	77
Whole house mechanical ventilation with heat recovery	20[a]	18.5	—	—	18.5	18	56	78
Micro and mini wind turbines	20	Too many depended variables in regards to location, time, placement. Stochastic energy source availability						
Mini CHP	14	10.5	25[b]	2.5[b]	10.5 (or 8)[b]	None	34 (or 10)[b]	73 (or 11)[b]
Micro CHP	14[c]	8[d]	25[b]	1.8[b]	8[d] (or 6.2)[b,d]	None	11[d] (or None)[b,d]	60 (or 50)[b]

[a]Most of the systems will last longer than expected with a decreased performance.
[b]Inland revenue: ECA—100% enhanced capital allowances for energy-saving investments; assuming small companies and individuals.
[c]Expected.
[d]Prices have not been given in the market yet. This figure may be further reduced by 30%. Analyses are based on two bedroom flats and houses.

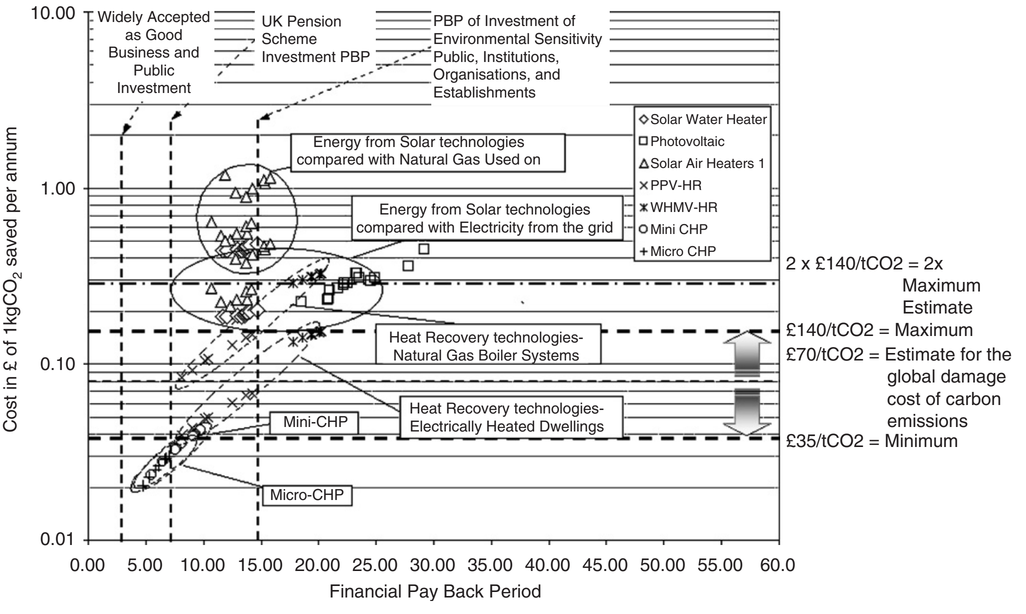

Fig. 3. CARB analyses of alternative energy technologies in housing including subsidies.

reduction from a ‘clients group’, as they are defined in Table 1, is required, this is identified.

Use of none building-structure-integrated PV technologies is not a financially viable option. It is suggested that the PV panels be used only when another construction material is replaced. Façade materials are the best replacement option. Solar heating technologies are more financial attractive; while the air-based technology is slightly beneficial over water-based considering total life cycle costs. HR technologies should be considered as a good investment especially in the existing aged housing stock. MVHR performs worst, but its financial viability is increased if it used for Summer cooling in solar-overheated dwellings, or if people with special medical problems requiring a continuous flow of fresh air. Usage of mini and micro WEG into or near buildings is limited by site topographic and climatic characteristics [16]. CHP co-generation is the most ‘profitable’ energy generation investment scenario.

4.2. *‘CARB financial analysis’ methodology*

Most of the new and renewable technologies are not generally used purely for the financial profit for the investor, but also for their environmental benefit. There is not a standard procedure for comparing all the technologies. The “CARB financial analysis” methodology is therefore proposed. CARB is an acronym for:

- *Carbon abatement*: as it evaluates the potential carbon-dioxide reduction from different technologies;
- *Relative*: as all the technologies examined are dependant on various primary sources; and

- *Balance*: as the cost of surplus CO_2, i.e. the difference between the existing and examined source, is quantified.

Two main variables are used for appraisal: the 'financial PBP' of the project and the 'cost of 1 kg CO_2 saved/annum'. These are plotted on the *x*–*y* axis of a graph, respectively. Note that the '*y*' axis is logarithmic as the 'cost of 1 kg CO_2 saved/annum' varies significantly between different technologies. On the graph, the minimum, average and maximum estimates of the social costs of carbon emissions are plotted. The minimum and maximum predictions are the horizontal thick dashed lines, with the average as a thin-dashed line between. In January 2002, a UK Government Economic Service (GES) working paper 'Estimating the Social Cost of Carbon Emissions' was published as a joint Defra–Treasury publication [17]. The GES paper suggested £70/tonne CO_2 (within a range of £35–£140 /tonne CO_2, i.e. £0.35–£1.4 /kg CO_2) as an illustrative estimate for the global damage cost of carbon emissions. The social costs, if the costs of the worst expected climate change disasters are doubled, are also included in the diagram. See horizontal, grey-coloured, long dash–dot line.

By using this methodology, the investor is able to compare the financial and environmental returns of different technologies.

4.2.1. Highest estimates

According to the proposed analysis, CHP technologies, in relation to the technologies examined, are the most cost effective technologies in regards to financial investment, and to the cost of potential savings of CO_2. Micro and mini CHP, in comparison to the other technologies, achieve the lowest carbon saving cost. There is little significant difference between micro and mini CHP.

The current operational life cycle cost of HR technologies is equivalent to the cost that will be imposed on society from a potential future climatic disaster related to climatic change from CO_2 emissions. The society will prepay the resolution of future environmental damages from current emissions.

Replacement of natural gas energy generator by solar technologies should be avoided. Even when solar technologies are replacing grid electricity, the carbon savings costs cannot be compared with that of other technologies, i.e. HRs. The ratio between the cost of 1 kg CO_2 saved and the recovery cost of its future potential damage is between one and two of the worst-case future environmental scenario.

Physical manifestations such as solar panels or wind turbines are conceptually easy to understand, but in practice, it maybe that the less visible energy generators are more valuable when assessed on CARB financial assessment criteria.

5. Conclusions

Even if the existing funding helps environmentally consciousness individuals and investors to consider new and renewable energy technologies, it does not help the public to invest in REST rather conventional investment schemes, i.e. pensions schemes. According to Table 2, a further 30% reduction, of the initial cost is required, without removing the current subsidies regime, in order to make all new and renewable energy systems competitive. This could be achieved by mutual attempts of the governmental institutions

and the systems, and technology suppliers. The cost reduction is crucial for the increase of installation in relation to current trends.

Most systems' prices are related to systems' sizes. Unpublished data indicate that the prices of solar water panels, with areas less than 50 m^2, could be reduced by up to 40% when panel systems of 300 m^2 are installed, as the size of tanks and balance of system devices will be reduced dramatically. This demonstrates a disadvantage to the lower budget investors who want to be involved in alternative technology projects.

The UK Enhanced Capital Allowance (ECA) further exacerbates the disadvantage as it reduces the benefit of the low-income investors. The ECA should be abolished and a new scheme should be initiated where the grant will be an equal percentage of the systems price for all the projects. This is suggested to be around 30%, and should be added to the existing schemes on top of other schemes, i.e. 60% grant will be available for solar panels if this percentage would be added to the 'Clear Skies' UK renewable energy funding scheme for all the candidates. Similarly for CHP, another scheme similar to the 'Clear Skies' should be initiated.

An alternative system, which could be adopted to promote equality between the investors, is the subsidy system currently used in Germany and France, i.e. standard subsidy price per unit of energy produced by alternative systems. It would be much more welcomed.

In regards to the 'CARB financial analysis', other building-based carbon reduction measures, i.e. increases of building envelope insulation, could be compared with alternative technologies by the proposed methodology. It is ideal for projects in which the actual cost of carbon saved is required, rather than the environmentally inconsequential financial pay back period of the investment.

The proposed methodology is also advantageous when it used for

- comparison of system based on the same technology, i.e. solar thermal, and with similar PBP, but with different operational characteristics, i.e. from different manufacturers;
- carbon abatement cost evaluation of installation of different technologies using the same natural resource, i.e. solar water systems compared with solar photovoltaic systems.

Finally, the 'CARB financial analysis' methodology has the potential to be used for other projects, such as municipal electricity generation from alternative technologies, where integrated financial and carbon cost assessment is required.

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